mage-Changes Caused by Astigmatism and by Correcting Cylinders.

— BY —

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IMAGE-CHANGES CAUSED BY ASTIGMATISM AND BY CORRECTING CYLINDERS.

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ILLUSTRATED.

The accompanying illustrations are so simple, easily understood and at the same time correct, that no apology for this paper seems necessary. These, at a glance, make clear what I have long taught as to the obliquity of retinal images in oblique astigmatism, the correctness of which, though at first denied by my critics, is now doubted by no one who has at all studied what has already appeared. A great deal of hard work, and the slight annoyance one always feels when criticised, although knowing the critics to be in error, might all have been avoided if these simple illustrations had occurred to me at the beginning.

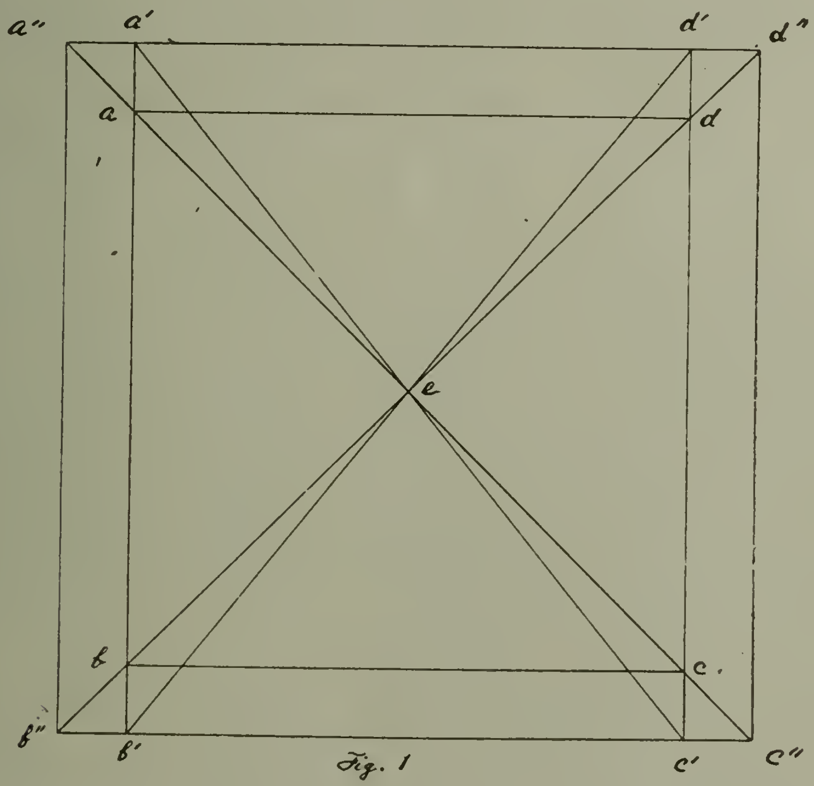

Fig. 1

Fig. 1 is complex, showing a square as seen by a non-astigmatic eye, as seen by an eye astigmatic according to the rule, and as seen by the latter after the astigmatism has been corrected by a plus cylinder. The rectangle *a-b-c-d* is the square seen by the non-astigmatic eye, and *a-c* and *d-b* show the diagonals of this square. The rectangle *a'-b'-c'-d'* is the figure seen by the astigmatic eye with the meridian of greatest curvature vertical. The axial rays from the ends of the lines *a-b* and *d-c* enter the eye through parts of the cornea parallel with the meridian of greatest curvature and so near to it that their refractive power is practically the same. The refraction of these axial rays from a and b, by the cornea, is such as to make them cross each other, on their way back to the retina, sooner than they would have done if their had been no astigmatism, hence their points of impingement on the retina are more widely separated and the line itself must be proportionately increased. The same is true of the axial rays from the ends of the line d-c. Hence it is clear that the line a-b must become the line a'-b' and the line d-c must become the line d'-c'. Because of the increase of the length of the lines a-b and d-c, the lines a-d and b-c are more widely separated, becoming lines a'-d' and b'-c'. and we have, not a square, but the rectangular parallelogram a'-b'-c'-d'. The diagonal a-c has been rotated towards the vertical and becomes a'-c'; and the diagonal d-b has been rotated in the opposite direction, but also towards the vertical, and becomes d'-b'. They have both been rotated by the refraction of the astigmatic cornea towards the meridian of greatest curvature. The image-changes effected by this astigmatic cornea are, as shown in the figure: increase in the length of the lines parallel with the meridian of greatest curvature, an increase in the distance between the lines parallel with the meridian of least curvature, and a corresponding rotation of the diagonals toward the meridian of greatest curvature. The proper plus cylinder placed before this eye gives such aid to the least curved meridian of the cornea as to make its retractive power exactly equal to the unaided refractive power of the meridian of greatest curvature. The result will be a lengthening of the horizontal lines a'-d' and b'-c' into the lines a''-d'' and b''-c'' and a displacement of the lines a'-b' and d'-c' until they become a''-b'' and d''-c''. Since two of the sides (a-b and d-c) of the square have been lengthened by the astigmatism and the remaining two sides (a-d and b-c) have been lengthened to exactly the same extent by the correcting plus cylinder, the figure a''-b''-c''-d'', seen by the corrected astigmatic eye, is a square. The cylinder, in changing the rectangular parallelogram a'-b'-c'-d' to the square a''-b''-c''-d'', has also rotated the diagonals a'-c' and d'-b' back to their original positions since the diagonal a''-c'' coincides exactly with the diagonal a-c, and the diagonal d''-b'' coincides with d-b.

If the astigmatism had been corrected by a minus cylinder the lines a'-b' and d'-c' would have been shortened into the lines a-b and d-c; the lines a'-d' and b'-c' would have been brought closer together, a'-d' becoming a-d and b'-c' becoming b-c, and the diagonals a'-c' and d'-b' would have been rotated back into the diagonals a-c and d-b respectively, so that the figure thus seen would be the square a-b-c-d. Thus it is shown that an astigmatic eye, corrected with a minus cylinder, sees the square with the same measurements as that seen by the non-astigmatic eye; while the square seen by the astigmatic eye, corrected with a plus cylinder, is magnified.

Turning the right side of Fig. 1 up it shows the image-changes when the meridian of greatest curvature is horizontal. In either case the lines parallel with the meridian of greatest curvature are made longer by the astigmatism, with a corresponding increase of distance between the lines parallel with the meridian of least curvature, and the diagonals are rotated towards the meridian of greatest curvature.

If there is astigmatism of one eye with the meridian of greatest curvature vertical and astigmatism of the same kind in the other eye with the meridian of greatest curvature horizontal, the former will see a square changed into a rectangular parallelogram longer sides vertical, while the latter would see the square similarly changed but with the longer sides horizontal. The images in such eyes would be dissimilar and could not be perfectly fused; correcting cylinders would make the images alike and thus make complete fusion possible.

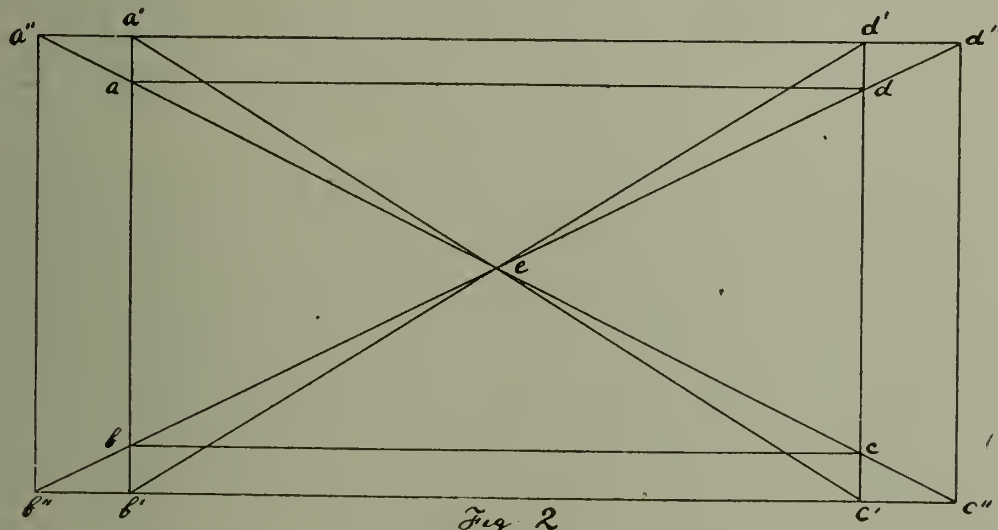

Fig 2

What is true of squares is true of rectangular parallelograms, as shown by Fig 2, in which there is the same proportionate lengthening of two of the sides by the astigmatism, and of the other two sides by the astigmatic correction with plus cylinders, also the same character of rotations of the diagonals, the principal meridians being vertical and horizontal.

Fig. 3 shows the image-changes when the astigmatism is oblique, the meridian of greatest curvature being at 135°. That part of the complex figure shown by *a-b-c-d* is a square as seen by a non-astigmatic eye. Looked at by the oblique astigmatic eye already mentioned, the diagonal *a-c* being at an angle of 135° is in a plane with the meridian of greatest curvature, while the diagonal *d-b* is in a plane with the meridian of least curvature. For reasons already given in discussing Fig. 1, the diagonal *a-c* is increased in length by the astigmatism into *a'-c'*, while the diagonal *d-b* is neither altered in length nor direction. The sides of the square not being parallel with the principal meridians must be rotated towards the meridian of greatest curvature, *a-b* becoming *a'-b*, *a-d* becoming *a'-d*, *b-c* becoming *b-c'* and *d-c* becoming *d-c'*. The figure *a'-b-c'-d* is a non-rectangular parallelogram leaning down and to the right. A plus cylinder correcting the astigmatism will increase the length of the diagonal *d-b* into *d'-b'* to exactly the length of the diagonal *a'-c'* and at the same time will rotate the line *a'-b* to *a'-b'*, *a'-d* to *a'-d'*, *c'-b* to *c'-b'* and *c'-d* to *c'-d'*, thus converting the non-rectangular parallelogram *a'-b-c'-d* into the magnified square *a'-b'-c'-d'*.

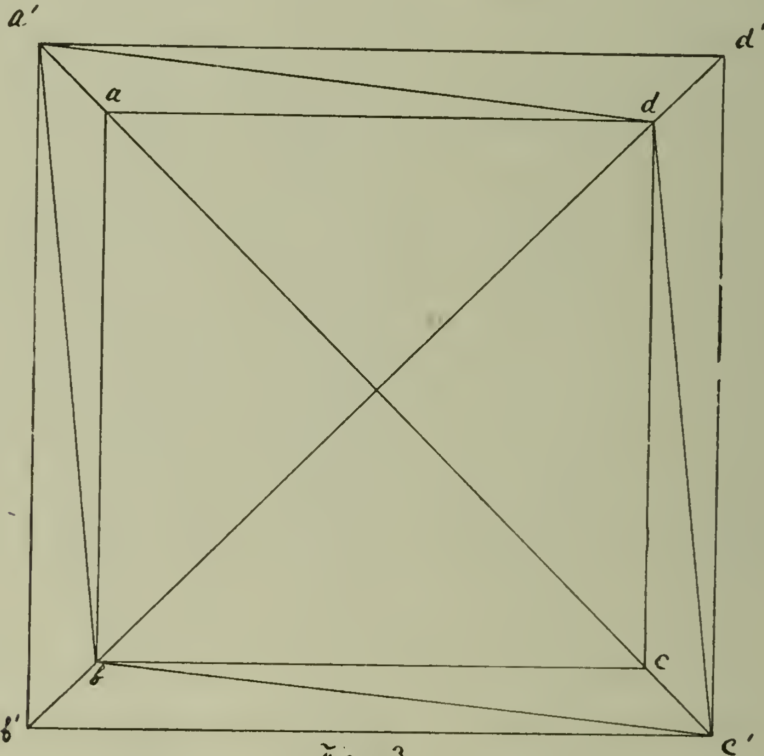

Fig. 3.

Turning the right side of Fig. 3 up, the image-changes are shown when the meridian of greatest curvature is at 45°. It is clear that, if the astigmatism is equal and of the same kind in the two eyes, the meridians of greatest curvature being parallel though oblique, the two images of a square held vertically will be distorted alike, and hence will fuse readily and completely. If the meridian of greatest curvature in one eye is at 135° and in the other at 45°, the image in each eye will be a non-rectangular parallelogram leaning in the opposite direction from the image in the other eye and cannot be perfectly fused, though an attempt at fusion will be made, in an effort on the part of the eyes to obey the supreme law of binocular single vision, the law of corresponding retinal points.

When the meridian of greatest curvature is vertical in one eye and horizontal in the other, the fusion of the dissimilar images is attempted by the recti muscles: if the upper or lower borders are to be fused it is done by the superior and inferior recti; if the right or left borders, the internal and external recti do the work; but the images, though of the same area, being differently shaped can never be perfectly fused by such a pair of uncorrected astigmatic eyes. Vertical astigmatism either against, or according to, the rule in both eyes involves only the ciliary muscles; vertical astigmatism according to the rule in one eye and against the rule in the other eye not only calls the ciliary muscle into activity but also calls the recti muscles into an abnormal or complicated action.* If with such eyes, vision having been fixed on the center of the square, the observer wishes to look at the upper border, the visual axis must be turned up by the two superior recti, the visual axes in the eye astigmatic according to the rule will have to move further than the one in the eye astigmatic against the rule, in order that the image of the upper border may fall on the horizontal meridian of each retina. Thus is interfered with the normal action of the superior and inferior recti muscles, which is to keep the visual axes in the same plane. The necessity for this complicated (as contrasted with the simple) function of the recti muscles may be seen by a further study of Fig. 1: Let a-b-c-d be the figure seen by the right non-astigmatic eye, and a'-b'-c'-d' be the same object as seen by the left eye astigmatic according to the rule. By no possibility can these figures be wholly fused, but different parts can be fused at will, but only as a result of the exercise of the complicated function of the recti muscles. If the vision has been fixed at the point of crossing of the diagonals, should an attempt be made to fuse the upper border of the object the visual axis of the right eye must be elevated only to the line a-b, while the visual axis of the left eye must continue to move until it reaches a'-b'. Fusion is thus effected by the one visual axis rising above the plane of the other. In the same way the complicated functions of the lateral recti muscles can be studied, there being no astigmatism in the right eye and astigmatism against the rule in the left. In the former case the vertically acting recti must continually perform the complicated function while the lateral recti perform only the simple function; in the latter case the vertically acting recti perform only the simple function while the lateral recti must continuously perform the complicated function. If in one eye the vertical astigmatism is according to the rule while in the other it is against the rule, then the recti muscles can perform their simple function only when the center of an object is looked at. In fusing any other parts, the complicated function must be performed. Only a correction of these cases of astigmatism by proper cylinders can give to the recti muscles the privilege of performing only their simple function. Astigmatism with the meridian of greatest curvature horizontal, in one eye, and no astigmatism in the other is worse than if both eyes were astigmatic with meridians of greatest curvature horizontal, for the reason that, in the latter, images in the two eyes being similar the recti muscles are called on to do only work that is normal; while in the former, images being dissimilar from side to side, the lateral recti muscles must do abnormal work (perform their complicated function). When their is no astigmatism in one eye and astigmatism with meridian of greatest curvature vertical in the other, the condition is worse than if both eyes were astigmatic with eridians of greatest curvature vertical, for the reason that in them latter, images being similar, the recti muscles must do only normal work; while in the former the vertically acting muscles must do abnormal work (perform their complicated function). The worst kind of vertical astigmatism exists when the meridian of greatest curvature is vertical in one eye and horizontal in the other, for then images are unlike both vertically and horizontally, and therefore require of all the recti muscles the performance of the complicated function, except when vision is fixed on the center of the object looked at.

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*All forms of Anisometropia demand of the recti muscles the performance of their complicated function.

In binocular astigmatism, the meridians of greatest curvature being parallel, whether vertical or oblique, images must be similar. This being true the extra-ocular muscles have to perform only their simple function — do such work as they must do in emmetropic eyes. The correction of such cases of astigmatism is important that the ciliary muscle may be relieved from abnormal work. In all other kinds of astigmatism correcting cylinders are needed to relieve not only the ciliary muscle but also one or more pairs of the extrinsic ocular muscles.

I have proved in this and in former papers that there is distortion of retinal images in oblique astigmatism; and that the distortion is in opposite directions in the two eyes when the meridians of greatest curvature diverge or converge above. This much is already generally conceded even by my former critics. To state that such images can be wholly fused would not be correct; but that fusion is attempted by the harmonious symmetric action of the oblique muscles cannot be denied without, at the same time, denying the existence of the supreme law of binocular single vision, the law of corresponding retinal points. The most daring would hardly deny the latter. Figure 3 shows how a square would be seen as a non-rectangular parallelogram (*a'-b-c'-d*) leaning down and in the direction of the meridian of greatest curvature, that meridian being at 135°, the eye being the right; turning the right side of the cut up (*c′-d-a′-b*) shows how the left eye, the meridian of greatest curvature at 45°, would see the square.

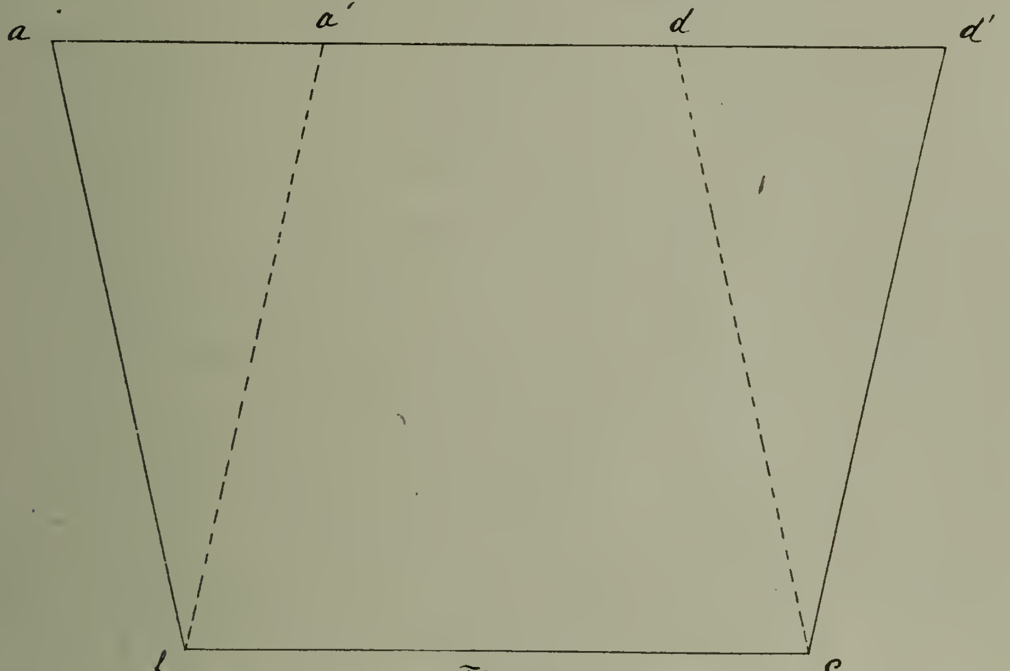

Fig. 4.

The accompanying cut, Fig. 4, shows how these two images are fused by the action of the superior oblique muscles. This trapezoid is not seen as a whole by the two eyes; while *a′-b-c-d* is seen in common by the two eyes, *a-b-a′* is seen by the right eye alone and *d-c-d′* is seen by the left eye alone Invert the cut and the trapezoid shows how a square would be seen by a pair of astigmatic eyes whose meridians of greatest curvature converge above. In such eyes the parallelogram images of the square would lean down and towards the corresponding side; and the fusion of these images into the trapezoid would be effected by the harmonious symmetric action of the inferior oblique muscles. In either of these cases the effort put forth by the two eyes is such as to completely fuse horizontal lines, as is shown in the lower part of Fig. 4, or in part, as is shown in the upper part of the same figure, the unfused parts of the upper border being directly continuous with the fused. In fusing the horizontal lines, the vertical lines are made to lean more, hence the trapezoid. It is as impossible for these uncorrected eyes to fuse all the sides of the images as it is for me to explain why, in the attempt at fusion, preference is given to the horizontal lines.

These are my reasons for believing that there is harmonious symmetric action of the oblique muscles in astigmatic eyes whose meridians of greatest curvature either diverge or converge above:—

1st. In all cases in which the meridians of greatest curvature diverge above, a square figure is seen by the two eyes as a trapezoid longer side above. The lower the degree of astigmatism and the slighter the variance of these meridians from the vertical or the horizontal, the more nearly does the trapezoid figure approach the form of a square. While in these uncorrected eyes it may appear so nearly a square, that the patient will say that it is such, nevertheless it is not a square, as is shown by the fact that, after the correcting cylinders have been worn a proper length of time, these patients will always say that a square is a square when seen through the lenses, and that it is a more or less marked trapezoid when the lenses are raised, to become a square again as soon as the lenses are lowered. By all oblique astigmatics with meridians of greatest curvature converging above, a square figure is seen as a trapezoid with the longer side below, though at first they may fail to so observe. In the former class of cases a square is seen by either eye alone as a parallelogram leaning down and towards the opposite side, while in the latter class of cases each eye alone sees a square as a parallelogram leaning down and towards the corresponding side. In my Edinburgh paper I showed how these images leaning in opposite directions were fused into a trapezoid by such a rotation of the eyes by oblique muscles as would bring the horizontal meridian of the retina of each eye into a position parallel with the upper and lower lines of the image.

2nd. Metamorphopsia through correcting cylinders approximately of the same strength, occurs only in those cases of astigmatism in which the meridians of greatest curvature diverge or converge above, and this metamorphopsia is always of a definite kind. In cases in which there is an equal quantity of astigmatism in the two eyes and the meridians of greatest curvature are parallel, whether vertical or oblique, the image-changes are precisely alike and therefore the images must fall on corresponding parts of the retinae. If the meridian of greatest curvature is at 135° in each eye, a square will throw a parallelogram image on each retina, leaning down and to the left. The two eyes together will see the square as a parallelogram leaning down to the left, precisely as each eye saw it. Fusion has been effected without abnormal action of either recti or oblique muscles, for the images had already fallen on corresponding retinal points. The proper cylinder placed before each eye at once changes the shape of the image from a parallelogram into a square, and the figure is seen as a square in both monocular and binocular vision. *There is no metamorphopsia following the correction of such astigmatics.* No muscle-habit has been formed in these cases and therefore no muscle-habit must be-broken. In like manner it could be shown that the image-changes in vertical astigmatism are such that like images are formed in the two eyes. A square is converted into a rectangular parallelogram by the astigmatism and this figure is reconverted into a square by the correcting cylinders. Through these cylinders each eye sees the figure as a square and the two together see it is a square. *No metamorphopsia follows the proper correction of such eyes.* But metamorphopsia can be produced in these eyes by revolving the axes of the cylinders so that they may no longer coincide with the meridians of best curvature. Revolve both axes in the arc of distortion for the superior obliques and a rect-angle becomes a trapezoid, longer side above; revolve the axes in the arc of distortion for the inferior obliques and the square becomes a trapezoid, longer side below. This metamorphopsia will never disappear until the cylinders are re-set properly; and the latter form of metamorphopsia is a source of less trouble to a patient than the former, for the reason that the inferior obliques are better able to do the abnormal work than are the superior obliques.

Metamorphopsia always follows, for a longer or shorter period, the wearing of cylinders given for the correction of astigmatism whose meridians of greatest curvature diverge or converge above. The character of this metamorphopsia is always of a definite kind in any given case, and may be foretold. Its duration is variable, but sooner or later it always disappears if the cylinders have been properly adjusted primarially. In these cases the astigmatism converts the square into a parallelogram, and the cylinder re-converts the parallelogram into a square. Each eye alone, with the aid of the proper cylinder correctly placed, will see a square as a square, but the two eyes together will for a time see the square as an imperfect trapezoid. If the case is one whose meridians of greatest curvature diverge above, in binocular vision through the cylinders the square will be seen as a trapezoid the longer side below, a new condition the reverse of the old, hence readily noticed. If the case is one whose meridians of greatest curvature converge above, in binocular vision through the cylinders a square will appear as an imperfect trapezoid longer side above, a new condition the reverse of the old, and hence readily noticed. In either case the parallelogram images, leaning in opposite directions, have been transformed into squares exactly alike, and through these cylinders each eye alone sees a square as a square, because the axis of the cylinder accurately coincides with the meridian of best curvature. If this coincidence should not be destroyed, in binocular vision, then there could no more be metamorphopsia in these cases than is found in those cases whose meridians of greatest curvature are parallel. If it never occurs in the latter because there is no muscle-habit to be broken, its occurrence in the former must be due to the fact that there has been a muscle-habit and that it tends to persist This habit has never been necessary in monocular vision, hence there is no disturbance of the relationship of cylinder axis and best meridian when a square is looked at with one eye, therefore it is seen as a square; in binocular vision the rotation of the eyes by the harmonious symmetric action of the obliques has always been a necessity, and the habit which has been formed by the obliques asserts itself, and when it does, there is a displacement of the best meridians, so that they no longer coincide with the cylinder axes, hence the metamorphopsia which is always observed by astimatics of 1 D. or more. This displacement produces distortion of images the opposite to the old distortion by the astigmatism, that is, if the images originally fused into a trapezoid with longer side above were non-rectangular parallelograms leaning down and towards the opposite side, the images now fused into an imperfect trapezoid longer side below, are non-rectangular parallelograms leaning down and towards the same side. In this case the displacement of the meridians has been effected by the superior obliques and the axes of the cylinders have been thus thrown into the arc of distortion for the inferior obliques. The moment the superior obliques lose their old habit, the meridians coincide with the axes of the cylinders and the metamorphopsia disappears. The same may be said of the inferior obliques, whose habit of abnormal action has been caused by astigmatism, whose meridians of greatest curvature converge above. In either case the metamorphopsia is new in kind, hence noticeable; but in all these cases it vanishes, usually disappearing sooner in those cases in which the meridians of greatest curvature diverge above. As soon as this new metamorphopsia disappears, the old kind can be easily brought out by raising the lenses while looking at a rectangle. It was harder to notice before, because the patient had always been accustomed to it. Now that a square has its correct shape with the lenses on, it at once appears as a trapezoid when they are raised

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